Consultative Committee for Space Data Systems

RECOMMENDATIONS FOR SPACE DATA SYSTEM STANDARDS

RADIO FREQUENCY AND MODULATION SYSTEMS

PART 1
EARTH STATIONS AND SPACECRAFT

CCSDS 401.0-B-1
BLUE BOOK

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These Recommendations reflect the consensus technical agreement of the following member agencies of the Consultative Committee for Space Data Systems (CCSDS):

- Centre National D'Etudes Spatiales (CNES)/France.
- Deutsche Forschungs-u. Versuchsanstalt fuer Luft und Raumfahrt e.V (DFVLR)/West Germany.
- European Space Agency (ESA)/Europe.
- Indian Space Research Organization (ISRO)/India.
- Instituto de Pesquisas Espaciais (INPE)/Brazil.
- National Aeronautics and Space Administration (NASA)/USA.
- National Space Development Agency of Japan (NASDA)/Japan.

The following observer agencies also concur with these Recommendations:

- British National Space Centre (BNSC)/United Kingdom.
- Chinese Academy of Space Technology (CAST)/People's Republic of China.
- Department of Communications, Communications Research Centre (DOC-CRC)/Canada.

These Recommendations are published by:

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STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed RECOMMENDATIONS and are not considered binding on any agency.

These RECOMMENDATIONS are issued by, and represent the consensus of, the CCSDS Plenary body. Agency endorsement of these RECOMMENDATIONS is entirely voluntary. Endorsement, however, indicates the following understandings:

- Whenever an agency establishes a CCSDS-related STANDARD, this STANDARD will be in accord with the relevant RECOMMENDATION. Establishing such a STANDARD does not preclude other provisions which an agency may develop.

- Whenever an agency establishes a CCSDS-related STANDARD, the agency will provide other CCSDS member agencies with the following information:

  -- The STANDARD itself.

  -- The anticipated date of initial operational capability.

  -- The anticipated duration of operational service.

- Specific service arrangements shall be made via memoranda of agreement. Neither these RECOMMENDATIONS nor any ensuing STANDARDS are a substitute for a memorandum of agreement.

No later than five years from its date of issuance, these RECOMMENDATIONS will be reviewed by the CCSDS to determine whether they should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or cancelled.

FOREWORD

This document, which is a set of technical Recommendations prepared by the Consultative Committee for Space Data Systems (CCSDS), is intended for use by participating space agencies in their development of radio frequency and modulation systems for earth stations and spacecraft.

These Recommendations allow implementing organizations within each agency to proceed coherently with the development of compatible Standards for the flight and ground systems that are within their cognizance. Agency Standards derived from these Recommendations may implement only a subset of the optional features allowed by the Recommendations herein, or may incorporate features not addressed by the Recommendations.

In order to establish a common framework within which the agencies may develop standardized communications services, the CCSDS advocates adoption of a layered systems architecture. These Recommendations pertain to the physical layer of the data system. Within the physical layer there are additional layers covering the technical characteristics of, and the policy constraints on, the communications services provided by the radio frequency and modulation systems. Recommendations contained in this document have been grouped into separate sections representing technical and policy matters.

These Recommendations for Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft, were developed for conventional near-earth and deep space missions having moderate communications requirements. Part 2 will be concerned with data relay satellites and will address the needs of users requiring services not provided by the earth stations covered in this document.

The CCSDS will continue to develop Recommendations for Part 1: Earth Stations and Spacecraft, to ensure that new technology and the present operating environment are reflected. New Recommendations for Part 1, which are developed in the future, will utilize the same format and be designed to be inserted into this book. Holders of this document should make periodic inquiry of the CCSDS Secretariat, at the address shown above, to make sure that their book is fully current.

Through the process of normal evolution, it is expected that expansion, deletion, or modification to this document will be required. Therefore, these Recommendations are subject to CCSDS document management and change control procedures which are defined in Reference [1].

DOCUMENT CONTROL

DOCUMENT	TITLE	DATE	STATUS/REMARKS
CCSDS 401.0 B-1	Recommendations for Space Data System Standards. Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft, Issue 1	January 1987	Original Issue

REFERENCES

[1] "Procedures Manual for the Consultative Committee for Space Data Systems", Issue 1, Consultative Committee for Space Data Systems, August 1985 or later issue.

[2] "Radio Frequency and Modulation Report", CCSDS Document, latest edition.

[3] "Radio Regulations", International Telecommunication Union, Geneva, Switzerland, 1982.

[4] "Recommendations and Reports of the CCIR", 1986 Plenary Assembly, Dubrovnik, Yugoslavia, 1986.

The latest issues of CCSDS documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

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1.0 INTRODUCTION

1.1 PURPOSE

This document recommends standards for radio frequency and modulation systems operated by the Consultative Committee for Space Data Systems (CCSDS) member and observer agencies.

1.2 SCOPE

These Recommendations are complementary to the CCSDS Radio Frequency and Modulation Report, Reference [2]. To obtain a complete understanding of a member or observer agency's tracking facilities, a reader should consult both documents. The Report broadly describes the RF and modulation characteristics of spacecraft tracking systems that the CCSDS member and observer agencies are planning for the post-1985 time period. It comprises a multiplicity of tables summarizing the technical characteristics of those systems.

The Recommendations contained in Part 1 focus upon the standardization of RF and modulation systems for earth stations and spacecraft. Part 2, now underway, will comprise Recommendations relating to data relay satellite systems. Unlike the Report, these Recommendations describe capabilities that the CCSDS agencies believe will be needed in future years. By recommending specific characteristics for these systems, the CCSDS hopes that the ensuing designs will be sufficiently similar so as to permit cross support of one agency's spacecraft by another agency's network.

These Recommendations do not provide specific designs. Rather they describe certain capabilities and provide technical characteristics in sufficient detail so that an agency may design compatible equipment. Additionally, guidelines are provided for the use of RF and modulation systems and their use of the RF spectrum. Therefore, subjects are assigned to one of two sections depending upon whether the focus is a technical capability or a policy matter.

The Recommendations are intended to promote an orderly transition to RF and modulation systems that are internationally compatible. The CCSDS believes that this course will not only assure better engineering practices but, also, that it will facilitate international cross-support agreements.

1.3 APPLICABILITY

These Recommendations apply to future implementation of RF and modulation systems. In combination with the RF and Modulation Report, Reference [2], this document describes the physical transport system used to carry data to and from spacecraft and earth stations.

1.4 DOCUMENT FORMAT

These introductory remarks are followed by two sections containing technical and policy recommendations, respectively. Often, it is not obvious to which section a recommendation belongs because it addresses both technical and policy matters. The decision usually turns upon whether the recommendation's content is quantitative or qualitative with the former being technical and the latter being policy.

Following the format established in the CCSDS RF and Modulation Report, technical recommendations are subdivided into modules describing the various subsystems. These are:

Earth-to-Space Radio Frequency
Command
Space-to-Earth Radio Frequency
Telemetry
Radio Metric
Spacecraft

Recommendations pertaining to each of these subjects are grouped together for easy accessibility. This approach facilitates cross referencing with the Report. If a reader wishes to determine whether an agency follows a specific CCSDS Recommendation, he need only turn to the corresponding section in the Report to determine that agency's capabilities.

Unlike other CCSDS Recommendations which focus upon specific topics such as channel coding or SFDUs, this document contains several subjects related to radio frequency and modulation systems. To promote brevity, clarity, and expandability, the authors have adopted a recommendation format which is similar to the one used by the International Telecommunications Union's (ITU) International Radio Consultative Committee (CCIR). Each Recommendation consists of brief statements and generally requires only one or two pages. Reasons justifying each recommendation are set forth in clear, crisp sentences. When appropriate, additional information providing the rationale for a Recommendation is included as an annex to this document. The modular form of this format permits inclusion of additional Recommendations as the CCSDS agencies' RF and modulation systems grow and as technology matures.

1.5 DEEP SPACE AND NON-DEEP SPACE

Much of the radio frequency standardization has already been accomplished by the International Telecommunications Union (ITU) and will be found in the Radio Regulations. The provisions contained in the ITU Radio Regulations, as well as applicable CCIR documents, are adopted and incorporated here by reference.

Four radiocommunication services are of interest to the CCSDS. In accordance with the ITU definitions these are: the Space Research Service, the Space Operation Service, the Earth Exploration Satellite Service, and the Meteorological Satellite Service.

Within the Space Research Service, a distinction is made between "Deep Space" and "non-Deep Space" spacecraft. Those bands allocated to "Space Research/Deep Space" shall only be used by spacecraft engaged in interplanetary research, whose range exceeds a specified distance.

The Radio Regulations establish this boundary for deep space at lunar distance. With the advent of spacecraft in highly elliptical earth orbits that go beyond lunar distance, or in orbits around the sun-earth libration points, frequency assignments based on the currently defined boundary can result in non-optimum use of the deep space bands.

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Within the Space Research Service, a distinction is made between "Deep Space" and "non-Deep Space" spacecraft. Those bands allocated to "Space Research/Deep Space" shall only be used by spacecraft engaged in interplanetary research, whose range exceeds a specified distance.

The Radio Regulations establish this boundary for deep space at lunar distance. With the advent of spacecraft in highly elliptical earth orbits that go beyond lunar distance, or in orbits around the sun-earth libration points, frequency assignments based on the currently defined boundary can result in non-optimum use of the deep space bands.

Pending redefinition by ITU, and in accordance with CCIR Recommendation 610, the CCSDS has agreed to consider 2 x 10 exp 6 km as the boundary of deep space wherever this is possible under the Radio Regulations. Pursuant to this agreement, frequencies for spacecraft remaining within 2 x 10 exp 6 km boundary would be assigned in bands not restricted to deep space. Such assignment is presently possible except for the 7190-7235 MHz band where the ITU requires that transmission to spacecraft beyond lunar distance must be in the 7145-7190 MHz band.

While the Radio Regulations contain a definition for deep space, they do not specifically name that zone lying closer to the earth. Thus, there is no internationally recognized term for non-deep space missions.

Range is important for two reasons. First, certain frequencies are reserved for spacecraft operating in deep space. Second, the RF and modulation characteristics may be different for the two categories.

To avoid confusion with the ITU definition for deep space, as well as to facilitate a discussion of project support for spacecraft at any distance, the following mission categories are used throughout these Recommendations:

Category A	Those missions having an altitude above the earth of less than, or equal to, 2 x 10 exp 6 km.
Category B	Those missions having an altitude above the earth of greater than 2 x 10 exp 6 km.

Figure 1.5-1 pictorially depicts the Category A and B mission regions.

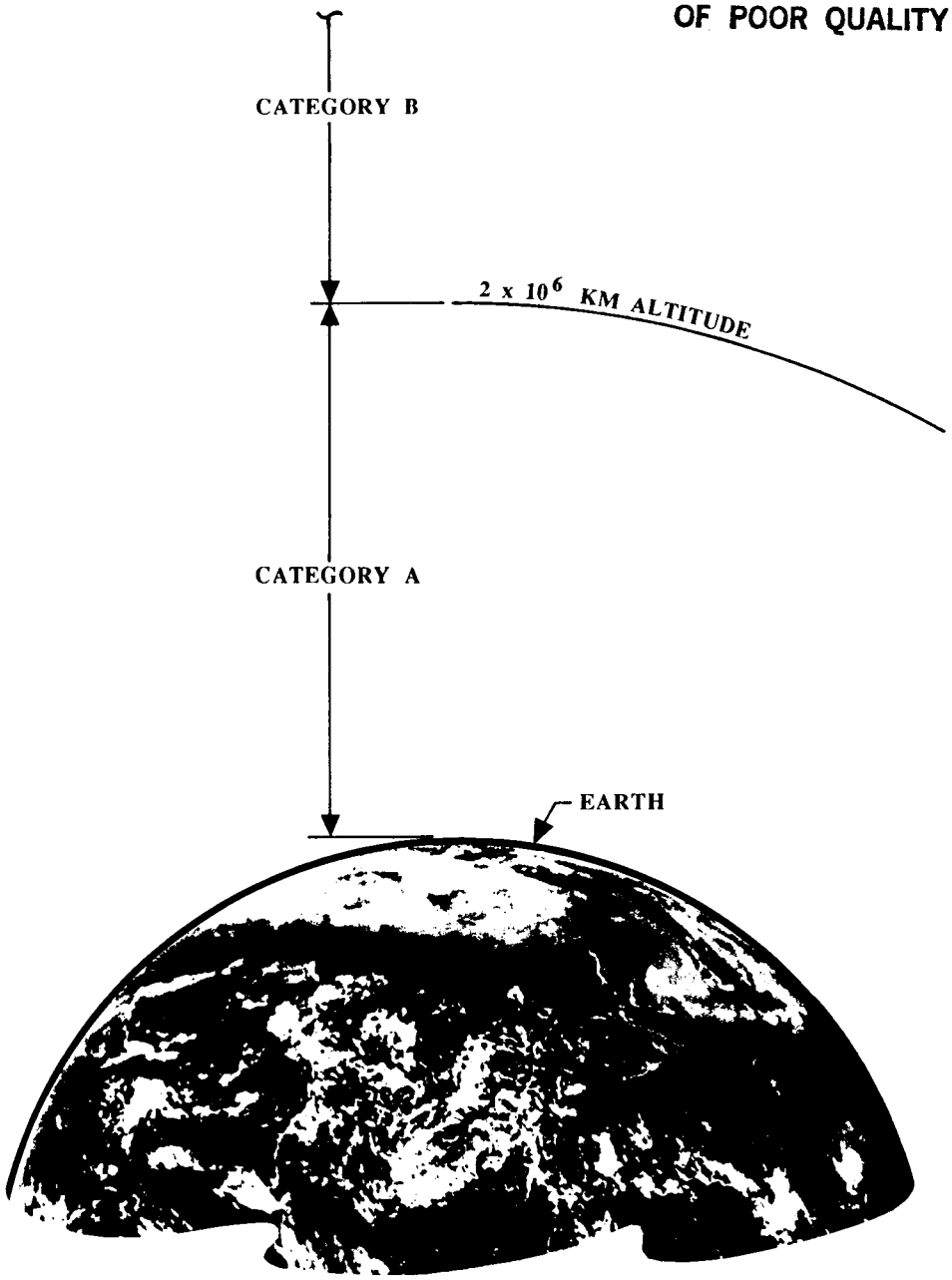

FIGURE 1.5-1 MISSION CATEGORIES

2.0 TECHNICAL RECOMMENDATIONS

Section 2 focuses upon the technical characteristics of RF and modulation systems for earth stations and spacecraft. Each recommended standard delineates a specific capability which the CCSDS agencies believe will be needed in future years. Some suggested standards argue for retaining existing facilities, while others propose developing systems not presently used by any agency. The goal is to set forth recommended standards with which the agencies can create a group of uniform capabilities.

To facilitate the document's use, this section has been subdivided into six modules, each containing an individual subject. These subjects have been arranged in the same order as found in the CCSDS Radio Frequency and Modulation Report. An additional subsection for spacecraft has been included in Section 2. Here, one can find those characteristics pertaining to spacecraft radio frequency and modulation systems.

Six tables corresponding to the six modules follow these introductory remarks. These tables contain the subject matter of each recommendation, its number, and a summary description. Using these tables, the reader can quickly locate specific recommendations contained in Section 2.

EARTH-TO-SPACE RF RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.1.1	Phase Modulation	Use with residual carriers
2.1.2	Circular Polarization	Use on earth-to-space RF links
2.1.3A	± (1-150) kHz; ± (1-500) kHz	Min Cat. A acquisition sweep range at 2 and 7 GHz
2.1.3B	± (1-300) kHz; ± (1-1000) kHz	Min Cat. B acquisition sweep range at 2 and 7 GHz
2.1.4A	500 Hz/s - 50 kHz/s	Min Cat. A acquisition sweep rate
2.1.4B	1 Hz/s - 10 kHz/s	Min Cat. B acquisition sweep rate
2.1.5	Pos. Voltage → Pos. Phase	Input voltage to carrier phase shift relationship
2.1.6	10 dB Carrier Suppression	Max carrier suppression resulting from all signals

TELECOMMAND RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.2.1		Maximum RSS Telecommand modulation index
2.2.2	8/16 kHz PSK Sine Subcarrier	Telecommand subcarrier types for Cat. A & B missions
2.2.3	NRZ-L,-M Mod w PSK Subcarrier	Telecommand data modulation of subcarrier
2.2.4	$4000/2^n$; n = 0, 1, 2,.....9	Range of telecommand bit rates
2.2.5	Subcarrier Characteristics	Frequency offset and stability

SPACE-TO-EARTH RF RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.3.1	Residual Carrier Receiving Systems	Use with low bit rate telemetry systems
2.3.2	Suppressed Carrier Modulation	Use with high bit rate telemetry systems
2.3.3A	± 150 kHz; ± 600 kHz	Min Cat. A acquisition sweep range at 2 and 8 GHz
2.3.3B	± 300 kHz; ± 1 MHz	Min Cat. B acquisition sweep range at 2 and 8 GHz
2.3.4A		Min Cat. A acquisition sweep rate
2.3.4B	1 Hz/s - 10 kHz/s	Min Cat. B acquisition sweep rate
2.3.5	Circular Polarization	Use on space-to-earth RF links
2.3.6	Pos voltage → Pos Phase	Input voltage to carrier phase shift relationship
2.3.7	$\pm 5 \times 10^{-13}$; $\pm 2 \times 10^{-12}$	Short- and long-term reference frequency stability
2.3.8	10 dB Carrier Suppression	Max Carrier Suppression resulting from all signals

TELEMETRY RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
2.4.1		Maximum telemetry modulation index for residual carrier systems
2.4.2	DNRZ (NRZ-M) Modulation	Use with suppressed carrier systems
2.4.3	Subcarriers and Frequencies	Use with low bit rate residual carrier systems
2.4.4	PSK Modulation	Use when subcarriers are employed
2.4.5	Sinewave/Squarewave	Subcarrier waveforms, Cat. A and B missions respectively
2.4.6	Subcarrier Characteristics	Frequency offset and stability
2.4.7	NRZ-L and SP-L Waveforms	Choice of PCM waveforms in residual carrier systems

RADIO METRIC RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY

SPACECRAFT RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
		TRANSPONDER TURNAROUND FREQ. RATIOS, CAT. A
2.6.1	221/240	2025-2110 MHz to 2200-2290 MHz.
2.6.2	749/880	7190-7235 MHz to 8450-8500 MHz
2.6.3	221/900	2025-2110 MHz to 8450-8500 MHz
2.6.4	765/240	7190-7235 MHz to 2200-2290 MHz
		TRANSPONDER TURNAROUND FREQ. RATIOS, CAT. B
2.6.1	221/240	2110-2120 MHz to 2290-2300 MHz.
2.6.2	749/880	7145-7190 MHz to 8400-8450 MHz
2.6.5	221/880	2110-2120 MHz to 8400-8450 MHz
2.6.6	749/240	7145-7190 MHz to 2290-2300 MHz

2.1.1 RF CARRIER MODULATION OF THE EARTH-TO-SPACE LINK

The CCSDS,

considering

(a) that most space agencies currently utilize spacecraft receivers employing phase-locked loops;

(b) that conventional phase-locked loop receivers require a residual carrier to operate efficiently;

(c) that phase modulation results in efficient demodulation;

recommends

that CCSDS agencies provide a capability to support phase modulation with a residual carrier for their earth-to-space links.

2.1.2 POLARIZATION OF EARTH-TO-SPACE LINKS

The CCSDS,

considering

(a) that a linear electric field polarization on links to spacecraft, having nearly omnidirectional antenna patterns, may vary considerably with aspect angle;

(b) that the aspect angle of a near-earth orbiting satellite varies greatly during a pass;

(c) that for satellites having a stable linear polarization in the direction of the earth station (e.g., geostationary satellites with suitable attitude stabilization or satellites using tracking antennas) the propagation effects such as Faraday rotation may cause substantial rotation in the received polarization at lower carrier frequencies;

(d) that automatic correction of rotation in the earth station's polarization adds undesirable complexity to the system;

(e) that most existing earth stations are equipped for RHC and LHC polarization;

recommends

(1) that CCSDS agencies use circular polarization on their earth-to-space RF links for telecommand and ranging;

(2) that payload service links use circular polarization in those cases where TTC is carried out in the payload service band or where on-board antennas are shared with payload functions;

(3) that the earth station be designed to switch between LHC and RHC polarization without causing an interruption of the transmitted carrier exceeding 5 seconds in those cases where changes of polarization are desired.

2.1.3A TRANSMITTER FREQUENCY SWEEP RANGE ON EARTH-TO-SPACE LINKS, CATEGORY A

The CCSDS,

considering

(a) that the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and Category A spacecraft, can achieve values up to:

± 80 kHz at 2 GHz
± 300 kHz at 7 GHz;

(b) that the rest frequency uncertainties in spacecraft receivers are in the order of:

± 50 kHz at 2 GHz
± 200 kHz at 7 GHz;

(c) that the lock-in frequency range of spacecraft receivers is much smaller than the frequency deviations given in (a) and (b);

(d) that the doppler frequency shift can usually be predicted to an accuracy of better than ± 1 kHz;

(e) that most of the spacecraft receivers have a tracking range up to:

± 150 kHz at 2 GHz
± 500 kHz at 7 GHz;

(f) that the acquisition time should be kept to a minimum;

recommends

that the earth station's transmitter should have a minimum sweep range capability of at least:

± 1 kHz

and a maximum sweep range capability of:

± 150 kHz at 2 GHz
± 500 kHz at 7 GHz.

2.1.3B TRANSMITTER FREQUENCY SWEEP RANGE ON EARTH-TO-SPACE LINKS, CATEGORY B

The CCSDS,

considering

(a) that the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and category B spacecraft, can achieve values up to:

± 250 kHz at 2 GHz
± 900 kHz at 7 GHz;

(b) that the rest frequency uncertainties in spacecraft receivers are on the order of:

± 1 kHz at 2 GHz
± 4 kHz at 7 GHz;

(c) that the doppler frequency shift can usually be predicted to an accuracy of ± 1 kHz;

(d) that most of the spacecraft receivers have tracking ranges less than or equal to:

± 300 kHz at 2 GHz
± 1 MHz at 7 GHz;

(e) that the lock-in frequency range of spacecraft receivers is much smaller than the frequency deviations given in (a) and (b) above;

(f) that the effect on the radio link, resulting from variation in the columnar charged-particle content, is generally negligible;

(g) that the acquisition time should be kept to a minimum;

recommends

that the earth station's transmitter should have a minimum sweep range capability of:

± 1 kHz at 2 and 7 GHz

and a maximum sweep range capability of at least:

± 300 kHz at 2 GHz
± 1 MHz at 7 GHz.

2.1.4A TRANSMITTER FREQUENCY SWEEP RATE ON EARTH-TO-SPACE LINKS, CATEGORY A

The CCSDS,

considering

(a) that the rate of change of the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and Category A spacecraft, is smaller than:

3 kHz/s at 2 GHz
10 kHz/s at 7 GHz;

(b) that most of the spacecraft receivers have a phase-locked loop with a bandwidth (2 BLO) in the range 200 Hz to 800 Hz at their threshold;

(c) that the maximum permissible rate of input frequency variation for most types of spacecraft receivers is between 2 kHz/s and 30 kHz/s at their threshold;

(d) that the frequency sweep rate on the earth-to-space link should be chosen such that the total rate of frequency variation, resulting from both the transmitter's sweep rate and the orbital doppler rate, does not unlock the spacecraft's phase-locked loop;

(e) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that the earth station's transmitter should have a minimum frequency sweep rate capability of:

500 Hz/s

and a maximum frequency sweep rate capability of at least:

50 kHz/s.

2.1.4B TRANSMITTER FREQUENCY SWEEP RATE ON EARTH-TO-SPACE LINKS, CATEGORY B

The CCSDS,

considering

(a) that the rate of change of the doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and category B spacecraft, is smaller than:

60 Hz/s at 2 GHz
200 Hz/s at 7 GHz;

(b) that most of the spacecraft receivers have a phase-locked loop with a bandwidth (2BLO) in the range 10 Hz to 100 Hz at their threshold;

(c) that the maximum permissible rate of input frequency variation for this type of spacecraft receiver is between 6 Hz/s and 1 kHz/s at its threshold;

(d) that the maximum permissible rate of input frequency variation for signals above the receiver's threshold can be as much as 10 kHz/s;

(e) that the frequency sweep rate on the earth-to-space link should be chosen such that the total rate of frequency variation, resulting from both the transmitter's sweep rate and the orbital doppler rate, does not unlock the spacecraft's phase-locked loop;

(f) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that the earth station's transmitter should have a minimum frequency sweep rate capability of:

1 Hz/s

and a maximum frequency sweep rate capability of at least:

10 kHz/s.

2.1.5 RELATIONSHIP OF MODULATOR INPUT VOLTAGE TO RESULTANT RF CARRIER PHASE SHIFT

The CCSDS,

considering

that a clear relationship between the modulating signal and the RF carrier's phase is desirable to avoid unnecessary ambiguity problems;

recommends

that a positive-going voltage at the modulator input should result in an advance of the phase of the radio frequency signal.

NOTE: This Recommendation is also filed under reference 2.3.6

2.1.6 RF CARRIER SUPPRESSION ON EARTH-TO-SPACE LINKS FOR RESIDUAL CARRIER SYSTEMS

The CCSDS,

considering

that high modulation indices may make the residual carrier difficult to detect with a conventional phase-locked loop receiver;

recommends

that CCSDS agencies select modulation indices such that the reduction in carrier power, with respect to the total unmodulated carrier power, does not exceed 10 dB.

2.2.2 SUBCARRIERS IN TELECOMMAND SYSTEMS

The CCSDS,

considering

(a) that most space agencies presently utilize either 8 kHz or 16 kHz subcarriers for telecommand transmissions where data rates are less than or equal to 4 kb/s;

(b) that modulation schemes employing subcarriers reduce the interference to the RF carrier loop resulting from data sidebands;

(c) that PSK modulation is the most efficient type of digital modulation because of its bit error performance;

(d) that it is important to limit the occupied bandwidth;

recommends

that CCSDS agencies use a sine wave subcarrier for telecommand, with a frequency of either 8 kHz or 16 kHz, which has been PSK modulated.

2.2.3 CHOICE OF WAVEFORMS IN TELECOMMAND LINKS

The CCSDS,

considering

(a) that NRZ-L, -M waveforms result in efficient spectrum utilization;

(b) that present telecommand bit rates are generally less than or equal to 4 kb/s;

(c) that telecommand data sidebands are separated from the carrier by employing a PSK subcarrier;

(d) that NRZ-L waveforms result in very good signal-to-noise performance;

(e) that NRZ-M waveforms avoid ambiguity errors;

recommends

(1) that CCSDS agencies use NRZ-L, -M waveforms with PSK subcarriers for telecommand data;

(2) that due consideration be given to the bit transition density of the telecommand modulation to ensure proper operation of the spacecraft's receiving equipment.

2.2.4 RANGE OF TELECOMMAND BIT RATES

The CCSDS,

considering

(a) that many space agencies utilize PCM-PSK modulation for the telecommand links;

(b) that phase coherency between the PCM signal and the subcarrier facilitates system implementation;

(c) that subcarrier frequencies of either 8 kHz or 16 kHz are commonly used;

(d) that many space agencies have developed, or will develop, equipment using telecommand data rates in the range 8-4000 b/s;

recommends

(1) that CCSDS agencies provide telecommand bit rates in the range $4000/2^n$ b/s, where n = 0, 1, 2, ..., 9;

(2) that data bit and subcarrier transitions should coincide.

NOTE: A 4000 b/s rate should only be used with a 16 kHz subcarrier and care should be taken to ensure that harmful interactions with other signals do not occur.

2.2.5 TELECOMMAND SUBCARRIER FREQUENCY STABILITY

The CCSDS,

considering

(a) that the present use of subcarriers for modulating the earth-to-space RF links represents a mature technique for both Categories A and B missions and, therefore, is a well settled standard;

(b) that modifications of this standard imply costly changes to space agencies' networks;

recommends

that CCSDS agencies' earth stations be designed to provide telecommand subcarriers with characteristics which are equal to or better than:

Maximum Subcarrier Frequency Offset $\pm$ (2 x 10 exp -4)f_{sc};

Minimum Subcarrier Frequency Stability $\pm$ 1 x 10 exp -5
(1 second);

Minimum Subcarrier Frequency Stability $\pm$ 5 x 10 exp -5
(24 hours).

NOTE: f_{sc} = frequency of telecommand subcarrier.

2.3.1 RESIDUAL CARRIERS FOR LOW RATE TELEMETRY, SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that many space agencies own and/or operate earth stations for communication with spacecraft in which they have substantial investments;

(b) that these earth stations contain receiving equipment employing phase-locked loops;

(c) that conventional phase-locked loop receivers require a residual carrier component to operate properly;

(d) that most space agencies use autotrack systems for Category A missions, which need a residual carrier;

recommends

that CCSDS agencies retain residual carrier receiving systems in their earth stations for use with missions having low rate telemetry requirements.

2.3.2 SUPPRESSED CARRIERS FOR HIGH RATE TELEMETRY, SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that present technology makes the implementation of suppressed carrier systems practicable;

(b) that a comparison of carrier signal-to-noise ratios in a conventional residual carrier phase-locked loop with those in a suppressed carrier loop shows that the latter provides a substantial advantage over the former, frequently exceeding 10 dB;

(c) that a comparison of data symbol errors occurring in a conventional residual carrier phase-locked loop system with those occurring in a suppressed carrier loop system shows that the latter's performance is no worse, and frequently is better, than that of the former;

(d) that suppressed carrier systems lend themselves to compliance with PFD limits on the earth's surface more readily than do residual carrier systems;

(e) that some space agencies still use autotrack systems for their Category A missions, which need a residual carrier;

recommends

(1) that CCSDS agencies utilize suppressed carrier systems for space-to-earth communications when a residual carrier system would exceed the PFD limits on the earth's surface;

(2) that CCSDS agencies may provide a beacon for autotracking their Category A missions using suppressed carrier modulation.

2.3.3A EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RANGE, CATEGORY A

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that for the coherent turnaround mode, the doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency sweep range;

(c) that for the one-way mode, both the doppler frequency shift induced on the space-to-earth link and the frequency stability of the spacecraft's oscillator are the major factors to be considered in selecting the frequency sweep range;

(d) that the maximum rate of change of distance between the earth station and Category B spacecraft can reach values of up to 10 km/s;

(e) that the minimum frequency stability found in Category A spacecraft reference frequency oscillators is about $\pm$ 2 x 10 exp -5;

recommends

(1) that CCSDS agencies' earth station receivers be capable of frequency sweep ranges of at least:

$\pm$ 150 kHz at 2 GHz
$\pm$ 600 kHz at 8 GHz

(2) that CCSDS agencies provide a minimum sweep range that is consistent with their ability to predict the doppler frequency shift.

2.3.3B EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RANGE, CATEGORY B

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that in the coherent turnaround mode, the doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency sweep range;

(c) that the effect on the radio link, resulting from variation in the columnar charged-particle content, is generally negligible;

(d) that the maximum rate of change of distance between the earth station and Category B spacecraft can reach values of up to 35 km/s;

(e) that the minimum frequency stability found in Category B spacecraft reference frequency oscillators is about 1 x 10 exp -6;

recommends

that CCSDS agencies' earth station receivers be capable of frequency sweep ranges of at least:

± 300 kHz at 2 GHz
± 1 MHz at 8 GHz.

2.3.4B EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RATE, CATEGORY B

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that in the coherent turnaround mode, the doppler frequency rates induced on both the earth-to-space and the space-to-earth links are the major factors to be considered in selecting the earth station receiver's frequency sweep rate;

(c) that in the one-way mode, the doppler rate on the space-to-earth link and the earth station receiver's phase-locked loop bandwith (2BLO), with its resulting maximum permissible input frequency variation, are the major factors to be considered in selecting the sweep rate;

(d) that the rate of change of velocity between the earth station and category B spacecraft can reach values up to 10 m/s^2;

(e) that the earth station's receivers have phase-locked loop bandwidths (2BLO) in the range of 1 Hz to 1 kHz at their thresholds;

(f) that typical earth station receivers, operating in the 2 and 8 GHz bands, allow a maximum permissible rate of input frequency variation of between 1 Hz/s and 10 kHz/s;

(g) that the receiver's frequency sweep rate, plus the orbital doppler frequency rate, must not exceed the earth station receiver's ability to achieve phase-locked operation;

(h) that the acquisition time should be kept to a minimum for each mission phase;

(i) that a lower limit for the signal-to-noise ratio in the earth station receiver's phase-locked loop is approximately 8.5 dB;

recommends

that CCSDS agencies' earth station receivers, operating in the 2 and 8 GHz bands, should have a minimum sweep rate not exceeding 1 Hz/s and a maximum sweep rate of at least 10 kHz/s.

2.3.5 POLARIZATION OF SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that a linear electric field polarization on links from spacecraft, having nearly omnidirectional antenna patterns, may vary considerably with aspect angle;

(b) that the aspect angle of a near-earth orbiting satellite varies greatly during a pass;

(c) that for satellites having a stable linear polarization in the direction of the earth station (e.g., geostationary satellites with suitable attitude stabilization or satellites using tracking antennas), the propagation effects such as Faraday rotation may cause changes in the received polarization at lower carrier frequencies;

(d) that many earth stations are equipped with polarization diversity receivers;

(e) that many existing spacecraft TTC antenna designs provide circular polarization;

recommends

(1) that CCSDS agencies utilize LHC or RHC polarization for satellite TTC space-to-earth links unless sharing of equipment with payload functions requires a different approach;

(2) that automatic polarization tracking should be used for reception of satellite signals wherever possible;

(3) that polarization diversity reception should be used to meet the required system time constants at earth stations used for Category A missions.

2.3.6 RELATIONSHIP OF MODULATOR INPUT VOLTAGE TO RESULTANT RF CARRIER PHASE SHIFT

The CCSDS,

considering

that a clear relationship between the modulating signal and the RF carrier's phase is desirable to avoid unnecessary ambiguity problems;

recommends

that a positive-going voltage at the modulator input should result in an advance of the phase of the radio frequency signal.

NOTE: This Recommendation is also filed under reference 2.1.5

2.3.7 EARTH STATION OSCILLATOR REFERENCE FREQUENCY STABILITY

The CCSDS,

considering

(a) that most of the space agencies use a reference frequency standard to which the earth station's receiver and transmitter local oscillators are locked;

(b) that the short term frequency stability of the local oscillator substantially determines the range rate measurement's accuracy for Category A missions;

(c) that the long term frequency stability of the local oscillator substantially determines the range rate measurement's accuracy for Category B missions;

(d) that it is desirable for many missions to determine range rate with an accuracy of 1 mm/s or better;

(e) that the oscillator's frequency shall be sufficiently stable such that its effect upon the range rate measurement's error shall be significantly less than 1 mm/s;

(f) that, in addition to the foregoing, the long term stability of the local oscillator is also determined by the drift permitted in the earth station's clock which should not exceed 10 microseconds per month;

recommends

(1) that the short term frequency stability (Allan Variance) shall be better than $\pm$ 5 x 10 exp -13 for time intervals between 0.2 s and 100 s;

(2) that for Category B missions and for timekeeping, the long term frequency stability shall be better than $\pm$ 2 x 10 exp -12 for any time interval greater than 100 s.

2.3.8 RF CARRIER SUPPRESSION ON SPACE-TO-EARTH LINKS FOR RESIDUAL CARRIER SYSTEMS

The CCSDS,

considering

that high modulation indices may make the residual carrier difficult to detect with a conventional phase-locked loop receiver;

recommends

that CCSDS agencies select modulation indices such that the reduction in carrier power, with respect to the total unmodulated carrier power, does not exceed 10 dB.

2.4.2 MODULATING PCM WAVEFORMS FOR SUPPRESSED CARRIER SYSTEMS

The CCSDS,

considering

(a) that interaction between data sidebands and their RF carrier causes undesirable performance degradation;

(b) that suppressed carrier modulation schemes eliminate interaction between data sidebands and the RF carrier;

(c) that the necessary bandwidth for a suppressed carrier system with NRZ modulation is less than for a residual carrier system using Manchester or subcarrier modulation schemes;

(d) that the lack of a carrier reference at the demodulator results in a phase ambiguity of 180 degrees in the data;

(e) that this phase ambiguity is unacceptable and must be removed either by providing periodic, recognizable bit patterns for polarity determination, or by using a modulation that is insensitive to polarity;

(f) that DNRZ modulation is insensitive to polarity;

(g) that DNRZ inherently produces doublet errors, but bit pattern polarity determination schemes can result in the loss of entire frames;

(h) that some CCSDS member agencies use DNRZ suppressed carrier modulation in their relay satellites to reduce the necessary bandwidth while preventing data-carrier interaction;

(i) that either NRZ-M or NRZ-S is an acceptable DNRZ modulation scheme;

(j) that NRZ-M is currently in use;

recommends

(1) that suppressed carrier modulation schemes use NRZ-M waveforms;

(2) that in convolutionally encoded systems requiring conversion between NRZ-L and NRZ-M, the conversion from NRZ-L take place before the input to the Viterbi encoder, and the conversion from NRZ-M to NRZ-L take place after the output from the Viterbi decoder in order to maximize performance.

2.4.3 SUBCARRIERS IN LOW BIT RATE RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that at low bit rates, interaction between data sidebands and the residual RF carrier causes a performance degradation;

(b) that subcarrier modulation schemes eliminate interaction between data sidebands and the residual RF carrier;

(c) that some space agencies presently utilize ranging systems whose minor tones are below 20 kHz and whose major tone is 100 kHz, while others are planning to do so in the near future;

(d) that simultaneous ranging and telemetry operation should be possible;

recommends

(1) that CCSDS agencies use subcarriers with their residual carrier systems when transmitting low bit rates;

(2) that the subcarrier be placed between the 20 kHz and 100 kHz ranging tones, or above the 100 kHz tone.

2.4.4 PSK MODULATION FOR TELEMETRY SUBCARRIERS

The CCSDS,

considering

(a) that PSK modulation is a very efficient type of digital modulation because of its bit error performance;

(b) that many space agencies presently utilize PSK subcarrier modulation techniques, while others are planning to do so in the near future;

recommends

that CCSDS agencies use PSK subcarrier modulation if a telemetry subcarrier is employed.

2.4.5 TELEMETRY SUBCARRIER WAVEFORMS

The CCSDS,

considering

(a) that space agencies frequently employ subcarriers to separate data sidebands from the RF carriers;

(b) that for Category A missions, it is more important to limit the occupied bandwidth while for Category B missions, it is more important to minimize the susceptibility to in-band interference;

(c) that it is easier to generate square wave subcarriers;

recommends

(1) that for Category A mission telemetry transmissions, CCSDS agencies use sine wave subcarriers when they are modulated in the PSK mode;

(2) that for Category B mission telemetry transmissions, CCSDS agencies use square wave subcarriers when they are modulated in the PSK mode.

2.4.6 TELEMETRY SUBCARRIER FREQUENCY STABILITY

The CCSDS,

considering

(a) that the present use of subcarriers for modulating the space-to-earth RF links represents a mature technique for both Categories A and B missions and, therefore, is a well settled standard;

(b) that modifications of this standard imply costly changes to space agencies' networks;

recommends

that spacecraft radio frequency subsystems generating telemetry subcarriers be designed with characteristics equal to or better than:

Maximum Subcarrier Frequency Offset $\pm (1 \times 10^{-4}) f_{sc}$

Minimum Subcarrier Frequency Stability $\pm 1 \times 10^{-6}$
(short term)

Minimum Subcarrier Frequency Stability $\pm 1 \times 10^{-5}$
(long term)

NOTES: 1. f_{sc} = frequency of telemetry subcarrier,
2. Short term time intervals are less than or equal, 100 times the subcarrier's waveform period.

2.4.7 CHOICE OF PCM WAVEFORMS IN RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that NRZ waveforms rely entirely on data transitions for symbol clock recovery, and this recovery becomes problematical unless an adequate transition density can be guaranteed;

(b) that due to the presence of the mid-bit transitions, SP waveforms provide better properties for bridging extended periods of identical symbols after initial acquisition;

(c) that convolutionally encoded data have sufficient data transitions to ensure symbol clock recovery in accordance with the CCSDS recommended standards;

(d) that with coherent PSK subcarrier modulation, it is possible by adequate hardware implementation to bridge extended periods of identical symbols even when NRZ waveforms are used;

(e) that NRZ waveforms without a subcarrier have a non-zero spectral density at the RF carrier;

(f) that coherent PSK subcarrier modulated by NRZ data and using an integer subcarrier frequency to symbol rate ratio, as well as SP waveforms, have zero spectral density at the RF carrier;

(g) that the ambiguity which is peculiar to NRZ-L and SP-L waveforms can be removed by adequate steps;

(h) that use of NRZ-M and NRZ-S waveforms results in errors occurring in pairs;

(i) that it is desirable to prevent unnecessary decoder node switching by frame synchronization prior to convolutional decoding (particularly true for concatenated convolutional Reed-Solomon coding);

(j) that to promote standardization, it is undesirable to increase the number of options unnecessarily, and that for any proposed scheme, those already implemented by space agencies should be considered first;

recommends

(1) that for modulation schemes which use a subcarrier, the subcarrier to bit rate ratio should be an integer;

(2) that in cases where a subcarrier is employed, NRZ-L should be used;

(3) that for direct modulation schemes having a residual carrier, only SP-L waveforms should be used;

(4) that ambiguity resolution should be provided.

2.6.1 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 2025-2120 MHz AND 2200-2300 MHz BANDS

The CCSDS,

considering

(a) that a great number of space missions, which require coherency between the earth-to-space and space-to-earth links for development of navigational data, operate in the above frequency bands;

(b) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(c) that many CCSDS agencies have used the 221/240 turnaround ratio in their space missions for many years;

(d) that many CCSDS agencies have developed equipment using this ratio for their spacecraft and earth stations which represent a large financial investment;

(e) that the 221/240 turnaround frequency ratio adequately translates the 2025-2120 MHz band to the 2200-2300 MHz band;

recommends

(1) that CCSDS agencies continue to use the 221/240 turnaround frequency ratio for Category A and Category B space missions which are operating in the above bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.2 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 7145-7235 MHz AND 8400-8500 MHz BANDS

The CCSDS,

considering

(a) that a great number of space missions which require coherency between the earth-to-space and space-to-earth links for development of navigational data operate in the above frequency bands;

(b) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(c) that some CCSDS agencies have used the 749/880 turnaround ratio for several years and others are planning its use for the near future;

(d) that some CCSDS agencies have developed equipment using this ratio for their spacecraft and earth stations and others are planning to do so in the near future, representing a large financial investment;

(e) that the 749/880 turnaround frequency ratio adequately translates the 7145-7235 MHz band to the 8400-8500 MHz band;

recommends

(1) that CCSDS agencies use the 749/880 turnaround frequency ratio for their Category A and Category B space missions operating in the 7145-7235 and 8400-8500 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.3 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 2025-2110 MHz AND 8450-8500 MHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that future Category A space missions will use earth-to-space links in the 2025-2110 MHz band in conjunction with space-to-earth links in the 8450-8500 MHz band;

(b) that these space missions may require coherency between the earth-to-space and space-to-earth links for the development of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that the two frequency bands under consideration differ regarding the available bandwidth;

(e) that the lower and upper parts of the 2025-2110 MHz band are already rather densely occupied by long term missions and, consequently, they should be avoided;

(f) that for reasons of standardization of the on-board receiver design, a ratio between the two bands under consideration should be chosen in such a way as to conserve the number "221" of the "221/240" ratio for 2 GHz downlink/uplink systems;

(g) that for reasons of simplicity of on-board transmitter design, a ratio which can be divided down to small integers should be selected;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 221/900 for systems operating in the 2075-2087 MHz and 8450-8500 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.4 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 7190-7235 MHz AND 2200-2290 MHz BANDS, CATEGORY A

The CCSDS,

considering

(a) that future Category A space missions will use earth-to-space links in the 7190-7235 MHz band in conjunction with space-to-earth links in the 2200-2290 MHz band;

(b) that these space missions may require coherency between earth-to-space and space-to-earth links for the development of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that the two frequency bands under consideration differ regarding the available bandwidth;

(e) that the lower and upper parts of the 2200-2290 MHz band are already rather densely occupied by long term missions and, consequently, they should be avoided;

(f) that in many cases, the 2 GHz transponder will not be modified, and the 7 GHz earth-to-space link can be considered as optional;

(g) that a design goal of the 2/8 GHz transponder should be a simplicity of interfaces and system flexibility;

(h) that similarity of the circuit layout with the transponders developed for the deep space frequency bands may make hardware reuse possible;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 765/240 for systems operating in the 7190-7235 MHz and 2256-2270 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.5 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 2110-2120 MHz AND 8400-8450 MHz BANDS, CATEGORY B

The CCSDS,

considering

(a) that Category B space missions use earth-to-space links in the 2110-2120 MHz band in conjunction with space-to-earth links in the 8400-8500 MHz band;

(b) that many of these space missions require coherency between the earth-to-space and space-to-earth links for the development of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that for reasons of standardization of the on-board receiver design, a ratio between the two bands under consideration should be chosen in such a way as to conserve the number "221" of the "221/240" ratio for 2 GHz uplink/downlink systems;

(e) that for reasons of simplicity of on-board transmitter design, a ratio which can be divided down to small integers should be selected;

(f) that some CCSDS agencies utilize a turnaround frequency ratio of 221/880 and others are planning to do so in the near future;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 221/880 for their Category B missions operating in the 2110-2120 MHz and 8400-8450 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

2.6.6 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR THE 7145-7190 MHz AND 2290-2300 MHz BANDS, CATEGORY B

The CCSDS,

considering

(a) that Category B space missions will use earth-to-space links in the 7145-7190 MHz band in conjunction with space-to-earth links in the 2290-2300 MHz band;

(b) that many of these space missions require coherency between the earth-to-space and space-to-earth links for the generation of navigational data;

(c) that for space missions which require coherency, a turnaround frequency ratio must be defined;

(d) that for reasons of standardization of on-board receiver design, a turnaround frequency ratio containing the number "749" of the "749/880" ratio for the 7 GHz uplink/8 GHz downlink systems should be selected;

(e) that for reasons of standardization of on-board transmitter design, a turnaround frequency ratio containing the number "240" of the "221/240" ratio for 2 GHz uplink/downlink systems should be selected;

recommends

(1) that CCSDS agencies use a turnaround frequency ratio of 749/240 for Category B missions operating in the 7145-7190 MHz and 2290-2300 MHz bands;

(2) that this turnaround frequency ratio is only necessary for those space missions which require both cross support from other agencies' earth stations and coherency between the earth-to-space and space-to-earth links.

3.0 POLICY RECOMMENDATIONS

Section 2 concerns itself with the radio frequency and modulation systems' technical characteristics. By contrast, this chapter focuses upon radio frequency spectrum usage.

Rules governing a user's operations in the frequency bands are as important as the equipments' technical specifications. As crowding of the RF spectrum increases, standards become an imperative to order. In a broad sense the International Telecommunication Union (ITU) establishes high-level spectrum policy with its Radio Regulations. Here, the principal concern is with establishing lower-level guidelines promoting the most efficient use of the frequency allocations.

These policies are intended to supplement, not supplant, those promulgated by the ITU. This goal is reached by increasing the relevance of specific regulations to spacecraft communications. Each recommendation begins with applicable provisions of the ITU's Radio Regulations as a foundation and provides additional guidelines for the particular application.

By establishing the following agreements, the CCSDS agencies hope to significantly reduce spectrum congestion. Then, the potential for mutual interference in spacecraft communications should decrease accordingly.

POLICY RECOMMENDATION SUMMARY

REC. NO.	RECOMMENDED CHARACTERISTICS	RECOMMENDATION SUMMARY
3.1	Typical System Parameters	Efficient use of the 2 GHz band
3.2	10 MHz Bandwidth Limitation	Cat. A mission bandwidth restriction at 8 GHz
3.3	13.25 - 15.35 GHz	Use for Cat. A missions requiring large bandwidths
3.4	31.8 - 34.7 GHz	Reserve for Cat. B missions
3.5	Channel Center Frequencies	Cat. B mission channel frequency plan for 2, 7, 8, GHz
3.6	Earth-to-Space Power Level Limit	Restrict power level to minimum required for mission

3.1 EFFICIENT UTILIZATION OF THE 2 GHz BANDS BY SATELLITE MISSIONS

The CCSDS,

considering

(a) that frequency bands 2025-2110 and 2200-2290 MHz are shared co-equally by the following space services: Space Research, Space Operation, and Earth Exploration Satellite (EES);

(b) that these bands constitute mission bands for the Space Research and EES services and tracking, telemetry, and telecommand (TTC) bands for other space services making use of the Space Operation service allocations;

(c) that these bands are of prime importance for the satellite missions of CCSDS agencies and will remain so for many years to come as no comparable alternative frequency allocations are available;

recommends

that, in order to make maximum use of these bands for satellite missions of all kinds, appropriate technical and operational constraints be observed, particularly:

i The TTC systems for geostationary satellites should be designed and constructed to the general characteristics contained in CCIR Report 678, Dubrovnik, 1986, as set forth in Table 3.1-1. Given the state-of-the-art in satellite receiver technology as demonstrated by numerous existing 2 GHz TTC systems, higher earth station EIRPs are not desired and will be detrimental to the effective use of the RF spectrum as well as the geostationary orbit.

ii Space systems, which are designed to operate in mission bands other than 2025-2110 MHz and 2200-2290 MHz, but which utilize TTC systems within these bands, should limit the use of such TTC systems to launch, orbit insertion, and emergency operations in accordance with the definition of the Space Operation service (ITU/RR/25). By limiting the use of such TTC systems, the possibility of interference between spacecraft operating in the Space Operation, Space Research, and Earth Exploration Satellite (EES) services will be greatly reduced.

iii With a view to facilitating sharing of the 2 GHz bands, TTC and data transmission systems on spacecraft operating in the Space Research and Earth Exploration Satellite services should also be designed in such a way that the occupied bandwidths in the earth-to-space and space-to-earth links, as well as earth stations' EIRPs, are kept to a minimum.

3.1 EFFICIENT UTILIZATION OF THE 2 GHz BANDS BY SATELLITE MISSIONS (Continued)

TABLE 3.1-1

TYPICAL SYSTEM PARAMETERS AT 2 GHz

MODE	SYSTEM PARAMETERS	SPACE OPERATIONS (up to geostationary altitude)
Reception at earth station	Telemetry bandwidth Tracking bandwidth G/T, earth stations	100 kHz 400 kHz Approx. 20 dB/K
Transmission from earth stations	Telecommand bandwidth Tracking bandwidth EIRP, earth station	100 kHz 400 kHz Approx. 65 dBW

3.2 USE OF THE 8450-8500 MHz BAND FOR SPACE RESEARCH, CATEGORY A

The CCSDS,

considering

(a) that the 8450-8500 MHz band contains the only primary worldwide allocation to the Space Research service below 40 GHz, affording it particularly good protection from interference;

(b) that the total allocated bandwidth is limited to 50 MHz;

(c) that CCIR Recommendation 610 sets the limit for Category A missions at 2,000,000 km instead of lunar distance as currently defined in the ITU Radio Regulations (cf. ITU/RR/169);

(d) that space missions to the region between lunar distance and 2,000,000 km will need spectrum accommodation outside the deep space bands, in accordance with (c);

(e) that space missions mentioned under (d) may have technical requirements, which can only be satisfied in the 8450-8500 MHz bands;

(f) that certain space missions have a 2/8 GHz coherency requirement, determined by mission objectives;

recommends

(1) that space missions requiring an occupied bandwidth, as defined in ITU/RR/147, of more than 20% of the available bandwidth (i.e., in excess of 10 MHz) should not be approved for a frequency assignment in the 8450-8500 MHz band without detailed consideration of their requirements;

(2) that space missions mentioned in (d), (e), and (f) above should be given priority for use of the 8450-8500 MHz band;

(3) that CCSDS agencies approve space missions with bandwidth requirements in excess of 10 MHz in the 8450-8500 MHz band only on a case-by-case basis and impose, where necessary, operational limitations on their use of this band.

3.3 USE OF THE 13.25-15.35 GHz BANDS FOR SPACE RESEARCH, CATEGORY A

The CCSDS,

considering

(a) that frequency bands are allocated to the Space Research service between 13.25 and 15.35 GHz, i.e.,

13.25 - 13.40 GHz (earth-to-space)
13.40 - 14.30 GHz (no direction indicated)
14.40 - 14.47 GHz (space-to-earth)
14.50 - 15.35 GHz (no direction indicated)

(b) that these bands are allocated with a secondary status and consequently may not enjoy full protection from interference at all sites and all times;

(c) that these bands were found feasible for use with near-earth satellites in CCIR Recommendation 364;

(d) that a link near 15 GHz may provide about 1.5-2.5 dB improvement in the space-to-earth link compared to the current 8 GHz band, while a link near 33 GHz may provide 5.0-7.7 dB improvement compared to 8 GHz;

(e) that the limits of power flux density on the earth's surface for the 13.4-15.35 GHz bands are specified by CCIR Recommendation 510-1 to be:

-148 dB (W/m^2) in any 4 kHz band for angles of arrival between 0 and 5 degrees above the horizontal plane;

-148 + 0.5 (delta - 5) dB (W/m^2) in any 4 kHz band for angles of arrival, delta (degrees) between 5 and 25 degrees above the horizontal plane;

-138 dB (W/m^2) in any 4 kHz band for angles of arrival between 25 and 90 degrees above the horizontal plane;

(f) that these PFD limits allow operation of earth stations with G/Ts of typically 35-40 dB/K;

3.3 USE OF THE 13.25-15.35 GHz BANDS FOR SPACE RESEARCH, CATEGORY A (continued)

recommends

that the 13.25-15.35 GHz frequency bands of the Space Research service be used for Category A satellites, particularly with those missions having requirements for large bandwidths, which cannot be accommodated in other frequency bands of this service (such as in the 2 and 8 GHz bands).

NOTE: The Tracking and Data Relay Satellite System (TDRSS) uses the 13.25 to 15.35 GHz band with the 13.4 to 14.0 GHz portion being used for space-to-earth and TDRSS-to-user (satellite) transmissions. This lower portion of the band is susceptible to interference from Category A missions and consequently should be used with due consideration to the TDRSS use. (Sharing of this portion of the band may be feasible in certain circumstances, e.g., if transmissions of the near-earth spacecraft are pointed at the earth only and are restricted to those parts of the orbit where no interference will be carried to the White Sands, NM TDRSS earth station.)

3.4 USE OF THE 31.8-34.7 GHz BANDS FOR SPACE RESEARCH, CATEGORY B

The CCSDS,

considering

(a) that as spectrum usage increases, the potential for radio frequency interference (RFI) becomes greater;

(b) that telemetry links from missions in deep space, having very weak signals at the earth stations, are particularly susceptible to RFI;

(c) that frequency bands above 15 GHz are currently less crowded than those below 15 GHz;

(d) that allocated bands that are practicable with current or near future technology exist near 33 GHz, in particular:

FREQUENCY ALLOCATIONS IN THE SPACE RESEARCH SERVICE

FREQUENCY BAND (GHz)	DIRECTION	ALLOCATION STATUS
31.8-32.3	space-to-earth	Secondary*
34.2-34.7	earth-to-space	Secondary*

(e) that a link near 15 GHz may provide about 1.5-2.5 dB improvement in the space-to-earth link compared to the current 8 GHz band, while a link near 33 GHz may provide 5.0-7.7 dB improvement compared to 8 GHz;

(f) that a link near 15 GHz may provide about 5 dB improvement in the earth-to-space link compared to the current 7 GHz band, while a link near 33 GHz may provide an improvement of 10 dB compared to 7 GHz;

(g) that the allocations near 15 GHz and near 33 GHz are secondary; however, the 33 GHz allocation is primary in the U.S., Spain, and Australia, providing it with more protection from interference than is provided to the 15 GHz band;

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* Primary for deep space in the U.S., Spain, and Australia. Primary for space research in Bulgaria, Cuba, Hungary, Mongolia, Poland, the German Democratic Republic, Czechoslovakia, and the U.S.S.R.

3.4 USE OF THE 31.8-34.7 GHz BANDS FOR SPACE RESEARCH, CATEGORY B (Continued)

(h) that further consideration will have to be given to sharing considerations for either the 15 or 33 GHz bands. However, the 33 GHz band is somewhat better protected;

recommends

(1) that the frequency band:

31.8-32.3 GHz be utilized for Space Research (space-to-earth, Category B only);

34.2-34.7 GHz be utilized for Space Research (earth-to-space, Category B only);

(2) that CCSDS agencies utilize the bands near 33 GHz for communications with Category B missions in preference to those allocated to deep space near 13 and 17 GHz;

(3) that channel plans and transponder turnaround frequency ratios be developed as soon as possible linking the bands near 33 GHz to the 2, 7, and 8 GHz, Category B bands;

(4) that further consideration be given to the allocation status and the study of sharing criteria for the 31.8-32.3 and 34.2-34.7 GHz bands.

3.5 CHANNEL FREQUENCY PLAN FOR 2, 7, AND 8 GHZ, CATEGORY B

The CCSDS,

considering

(a) that channel frequency plans for Category B missions exist for the 2, 7, and 8 GHz bands while others are being developed for the 32 and 34 GHz bands;

(b) that the sets of channel frequency pairs in these existing plans are based upon the recommended turnaround ratios;

(c) that members of the Space Frequency Coordination Group (SFCG) have resolved to select frequencies for their Category B missions from the existing channel frequency plans;

(d) that most past, existing, and planned Category B missions have assigned frequencies that were selected on the basis of these existing channel frequency plans;

(e) that CCSDS agencies conducting Category B missions have coordinated the selection of frequencies from those embodied in the existing channel frequency plans in order to avoid interference between missions;

recommends

(1) that CCSDS agencies select frequencies for their Category B missions operating in the 2, 7, and 8 GHz bands from the channel frequency plan contained in Table 3.5-1;

(2) that frequency selection be coordinated with an appropriate organization, such as the SFCG, to ensure the orderly use of the channel frequency plan.

3.5 CHANNEL FREQUENCY PLAN FOR 2, 7, AND 8 GHZ, CATEGORY B (Continued)

TABLE 3.5-1: CHANNEL CENTER FREQUENCIES

Channel	2110-2120 MHz Uplink Channel Center Frequency (MHz)	2290-2300 MHz Downlink Channel Center Frequency (MHz)	7145-7190 MHz Uplink Channel Center Frequency (MHz)	8400-8450 MHz Downlink Channel Center Frequency (MHz)
1		2290.185185	7147.286265	
2		2290.555556	7148.442131	
3		2290.925926	7149.597994	
4		2291.296296	7150.753857	
5*	2110.243056	2291.666667	7151.909724	8402.777780
6	2110.584105	2292.037037	7153.065587	8404.135803
7	2110.925154	2292.407407	7154.221450	8405.493826
8	2111.266204	2292.777778	7155.377316	8406.851853
9	2111.607253	2293.148148	7156.533179	8408.209876
10	2111.948303	2293.518519	7157.689045	8409.567903
11	2112.289352	2293.888889	7158.844908	8410.925927
12	2112.630401	2294.259259	7160.000771	8412.283950
13	2112.971451	2294.629630	7161.156637	8413.641977
14	2113.312500	2295.000000	7162.312500	8415.000000
15	2113.653549	2295.370370	7163.468363	8416.358023
16	2113.994599	2295.740741	7164.624229	8417.716050
17	2114.335648	2296.111111	7165.780092	8419.074073
18	2114.676697	2296.481481	7166.935955	8420.432097
19	2115.017747	2296.851852	7168.091821	8421.790124
20	2115.358796	2297.222222	7169.247684	8423.148147
21	2115.699846	2297.592593	7170.403550	8424.506174
22	2116.040895	2297.962963	7171.559413	8425.864197
23	2116.381944	2298.333333	7172.715276	8427.222220
24	2116.722994	2298.703704	7173.871143	8428.580248
25	2117.064043	2299.074074	7175.027006	8429.938271
26	2117.405092	2299.444444	7176.182868	8431.296294
27	2117.746142	2299.814815	7177.338735	8432.654321
28	2118.087191		7178.494597	8434.012344
29	2118.428241		7179.650464	8435.370371
30	2118.769290		7180.814838	8436.738395
31	2119.110339		7181.962190	8438.086418
32	2119.451389		7183.118056	8439.444445
33	2119.792438		7184.273919	8440.802468
34**			7185.429783	8442.160493
35			7186.585617	8443.518517
36			7187.741511	8444.876542
37			7188.897375	8446.234566
38				8447.592591
39				8448.950616

* Channels 5-27 are fully coherent in all four bands.

** Channels 34-39 frequencies are estimates only.

3.6 LIMITATIONS ON EARTH-TO-SPACE LINK POWER LEVELS

The CCSDS,

considering

(a) that spectral occupation of frequency bands used by space agencies is increasing rapidly;

(b) that in many cases the same frequencies will be shared by several spacecraft;

(c) that excessive EIRP levels radiated from earth stations will make frequency sharing increasingly difficult and result in inefficient use of the radio frequency spectrum;

(d) that Pc/No, Eb/No, and the minimum signal level required due to the limitations of the receiver's dynamic range determine the required EIRP from the earth station;

(e) that the required signal level at the spacecraft's receiver input is frequently the dominant parameter determining the EIRP required from the earth station;

recommends

(1) that CCSDS agencies limit the EIRP levels on the earth-to-space links to those realistically required for safe spacecraft operation which can be achieved in the following ways:

- CCSDS agencies avoid using high power transmitters having a fixed output and adjust their transmitted power level to the minimum needed to meet project requirements;

- CCSDS agencies obtain the required EIRP by using reasonable antenna diameters in order to reduce both sidelobe radiation and transmitter power levels (Guideline: antenna diameter/RF wavelength equal to or greater than 70);

- CCSDS agencies place CCIR Recommendation 465-1 as a requirement in antenna specifications;

(2) that spacecraft equipment designers should endeavor to provide equal margins for Pc/No, Eb/No and the minimum signal required to fall within the receiver's dynamic range.

4.0 GLOSSARY OF TERMS

BLO	Loop bandwidth, one sided
b/s	Bits per second
Category A Missions	Those missions whose altitude above the earth is less than, or equal to, 2 x 10 exp 6 km.
Category B Missions	Those missions whose altitude above the earth is greater than 2 x 10 exp 6 km.
CCIR	International Radio Consultative Committee
CCSDS	Consultative Committee for Space Data Systems
COHER or Coh	Coherent
dB	Decibel(s)
dB/K	Decibels per kelvin
dBW	Decibel(s) relative to one watt
DNRZ	Differential non return to zero
Eb	Energy per data bit
Eb/No	Energy per data bit in a 1 Hz bandwidth
EES	Earth Exploration Satellite
EIRP	Equivalent isotropically radiated power
E/S	Earth-to-space
exp	Exponent
f_{sc}	Subcarrier frequency
GHz	Gigahertz
G/T	Antenna gain divided by system noise temperature
Hz	Hertz
ITU	International Telecommunication Union
ITU/RR	ITU Radio Regulations
k	Kilo
K	Kelvin
kb/s	Kilobits per second
kHz	Kilohertz
km	Kilometer(s)
LHC	Left-hand circular (polarization)
M	Mega (million)
m	Meter(s)

4.0 GLOSSARY OF TERMS (Continued)

MHz	Megahertz
NRZ	Non-return to zero
NRZ-L	Non-return to zero-level
NRZ-M	Non-return to zero-mark
NRZ-S	Non-return to zero-space
Pc	Carrier power
PCM	Pulse code modulation
PFD	Power flux density
PSK	Phase shift keying
RF	Radio frequency
RFI	Radio frequency interference
RHC	Right-hand circular (polarization)
RSS	Root sum square
s	Second(s)
S/E	Space-to-earth
SFDU	Standard Format Data Unit
SFCG	Space Frequency Coordination Group
SNR	Signal-to-noise ratio
SP	Split phase
TBD	To be determined
TDRSS	Tracking and Data Relay Satellite System
TTC	Tracking, telemetry, and command
W/m exp 2	Watts per square meter